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Inconsistent forecasting of the acceleration of northward-moving tropical cyclones entering the domain of the mid-latitude westerlies has been a long-standing weakness in tropical cyclone forecasting. The tracks of tropical cyclones traversing a relatively high-density data area of the western North Pacific have been analyzed to verify the acceleration phenomenon and to correlate the movement with features of the upper-tropospheric wind field. The resultant forecast technique is described and the results obtained with its use during the 1982 tropical cyclone season are presented.

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Predicting the Acceleration of Northward-Moving Tropical Cyclones Using Upper-Tropospheric Winds

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CONTENTS

ABSTRACT

Inconsistent forecasting of the acceleration of northward-moving tropical cyclones entering the domain of the mid-latitude westerlies has been a long-standing weakness in tropical cyclone forecasting. The tracks of tropical cyclones traversing a relatively high-density data area of the western North Pacific have been analyzed to verify the acceleration phenomenon and to correlate the movement with features of the upper-tropospheric wind field. The resultant forecast technique is described and the results obtained with its use during the 1982 tropical cyclone season in the western North Pacific are presented.

I. INTRODUCTION.

Investigations into the behavior of recurving tropical cyclones in the western North Pacific for 1970-1979 were conducted by Huntley (1981) and for 1945-1969 by Burroughs and Brand (1972). Each investigation showed substantial evidence of a rapid increase in tropical cyclone movement after recurvature. Efforts by Huntley to correlate these speeds to a first order differential equation of motion did not produce forecast results better than the official JTWC warnings. Burroughs and Brand's investigation revealed that the speed of movement after recurvature is a function of the time of year, the meteorological character of the tropical cyclone, and the synoptic environment. Forecast equations (Table 1) were developed using linear regression techniques to predict tropical cyclone movement after recurvature. Unfortunately, these equations have never been fully incorporated into the JTWC forecast development routine to determine the value of their predictive skill. However, it will be shown later that significant accelerations are common to more than just "recurving" tropical cyclones; thus, these equations may not be applicable to a sufficient number of forecast situations to be considered adequate for use by forecasters.

An investigation of recurving tropical cyclones was also conducted by Bao and Sadler (1982) for the period 1970-1979. Their analyses of upper-tropospheric winds poleward of recurving tropical cyclones revealed a high correlation between the speed of movement after recurvature, and the observed 500 mb and 200 mb winds (at and 12 hours prior to recurvature) along the subsequent tropical cyclone track. However, to apply this relationship, the forecaster must first decide on the track and then hope that there is a sufficient amount of upper wind data to develop a speed of movement forecast. Burroughs and Brand also found a correlation between the upper-level wind flow and tropical cyclone motion. Their analyses noted a relationship between monthly zonal winds at 350 mb and the zonal (west-to-east) component of tropical cyclone speed of movement. Unfortunately, Burroughs and Brand did not pursue this relationship and chose to relate tropical cyclone movement to lower-level (700 mb) troughs in the westerlies.

Xu and Gray (1982), utilizing a 21-year data set (1957-1977), investigated tropical cyclone motion south of, near, and north of, the subtropical ridge axis. Using surface and 500 mb analysis data they found that both the low-level and mid-level steering currents were in close agreement when tropical cyclones moved rapidly (>14 kt (27 km/hr)). Of particular interest are the results for tropical cyclones near, and north of, the subtropical ridge. They found that fast-moving tropical cyclones north of the ridge axis are associated with a high speed (>39 kt (72 km/hr)) air current as close as five degrees latitude to the tropical cyclone at the 500 mb level. Tropical cyclones near the ridge axis were

embedded in a moderately strong 500 mb flow from the southwest and were located east of a deep westerly trough. A direct relationship to upper-level (200 mb) winds was not reported due to a much more limited data base (1974-1977).

TABLE 1. FORECAST EQUATIONS FOR PREDICTING THE SPEED OF MOVEMENT OF TROPICAL CYCLONES 36 HOURS AFTER THE POINT OF RECURVATURE.

MONTH	FORECAST EQUATION
May, June, July	$S_{36} = (4.87 - 0.22S_r - 0.01I_r + 0.14\Delta S - 0.22\Delta D)S_r$
August	$S_{36} = (-3.81 + 0.16\Phi_r + 0.09D_r + 0.12\Delta S - 0.19\Delta D)S_r$
September	$S_{36} = 2.29S_r$
October	$S_{36} = (1.41 + 0.57S_r + 0.01I_r - 0.19\Delta S - 1.77\Delta\Phi + 0.48\Delta\lambda + 0.03\Delta\lambda_{trough})S_r$
November	$S_{36} = (3.55 - 0.14S_r + 0.16D_r + 0.02\Delta I + 0.31\Delta\lambda - 0.04\Delta\lambda_{trough})S_r$
December	$S_{36} = 2.86S_r$

DEFINITION OF PARAMETERS

S_{36} - Speed of movement of storms 36 hours after point of recurvature (knots)

S_r - Speed of movement at point of recurvature (knots)

I_r - Storm intensity (maximum surface wind) at recurvature (knots)

D_r - Storm size at recurvature (average diameter of outer closed surface isobar in degrees latitude)

Φ_r - Storm latitude at recurvature

ΔI - Storm intensity at recurvature minus value 24 hours prior to recurvature. That is, $\Delta I = I_r - I_{-24}$ (knots).

ΔS - Storm speed of movement at recurvature minus value 24 hours prior to recurvature. That is, $\Delta S = S_r - S_{-24}$ (knots).

ΔD - Storm size at recurvature (average diameter of outer closed surface isobar) minus value 24 hours prior to recurvature. That is, $\Delta D = D_r - D_{-24}$ (degrees latitude)

$\Delta\Phi$ - Storm latitude at recurvature minus value 24 hours prior to recurvature. That is, $\Delta\Phi = \Phi_r - \Phi_{-24}$.

$\Delta\lambda$ - Storm longitude at recurvature minus value 24 hours prior to recurvature. That is, $\Delta\lambda + \lambda_r - \lambda_{-24}$.

$\Delta\lambda_{trough}$ - Storm longitude at recurvature minus the longitude of the nearest 700-mb trough to the west of the storm (at 35N). That is, $\Delta\lambda_{trough} = \lambda_r - \lambda_{trough}$.

(From Burroughs and Brand, 1972)

II. BACKGROUND.

Forecasting significant accelerations associated with tropical cyclones entering the domain of the mid-latitude westerlies has been a long-standing problem for forecasters. A significant factor to overcome is the conditioning/experience gained from the high number of forecasts issued at low-latitudes and attempting to apply separate, or special sets of, rules to the mid-latitudes. In the low-latitudes most accelerations are fairly short-lived and are often followed by a marked decrease in speed; thus, not forecasting an acceleration in these latitudes might well produce an insignificant speed error over an extended period, i.e. 48 hours. However, because of the need to provide quality warnings to those activities and interests located outside of the tropics, e.g. Japan, it is of paramount importance to adequately anticipate, and then forecast, those accelerations that occur primarily within the mid-latitudes.

JTWC Annual Tropical Cyclone/Typhoon Reports have been replete with accounts that indicate forecasters have been aware that significant accelerations were common events when tropical cyclones moved northward into the mid-latitudes. A technique that would estimate where the acceleration would take place (based on real-time data) and provide some insight into the magnitude of the final acceleration has been lacking. Forecasters have thus beeen without systematic guidance and the forecasting of acceleration has been largely based on an individual forecaster's experience and willingness to dramatically increase a tropical cyclone's speed of movement.

The need for a good prediction technique to forecast acceleration of northward-moving tropical cyclones can be exemplified by Typhoon Tip (October, 1979), which followed Typhoon Owen by less than three weeks. Owen, as depicted in Figure 1, moved northward along 130E at speeds less than 6 kt (11 km/hr) prior to accelerating toward the northeast and eventually reaching a maximum speed of 47 kt (87 km/hr) as extratropical transition took place. If recent experience with these accelerations is thought to be instructive, then as Typhoon Tip turned northward near 128E (Figure 2), JTWC forecasters must have been well aware of the potential for a rather sudden and dramatic acceleration. Indeed, Tip did accelerate toward the northeast, subsequently attaining a speed of 48 kt (89 km/hr) prior to extratropical transition. However, as shown in Table 2, the official JTWC forecasts did not anticipate Tip's acceleration and once it began, the forecasts never approached the speeds of movement that occurred during the acceleration period. Thus, it is reasonable to assume that experience alone is not sufficient to overcome the problems involved with producing the speed of movement forecasts necessary for tropical cyclones in the mid-latitudes.

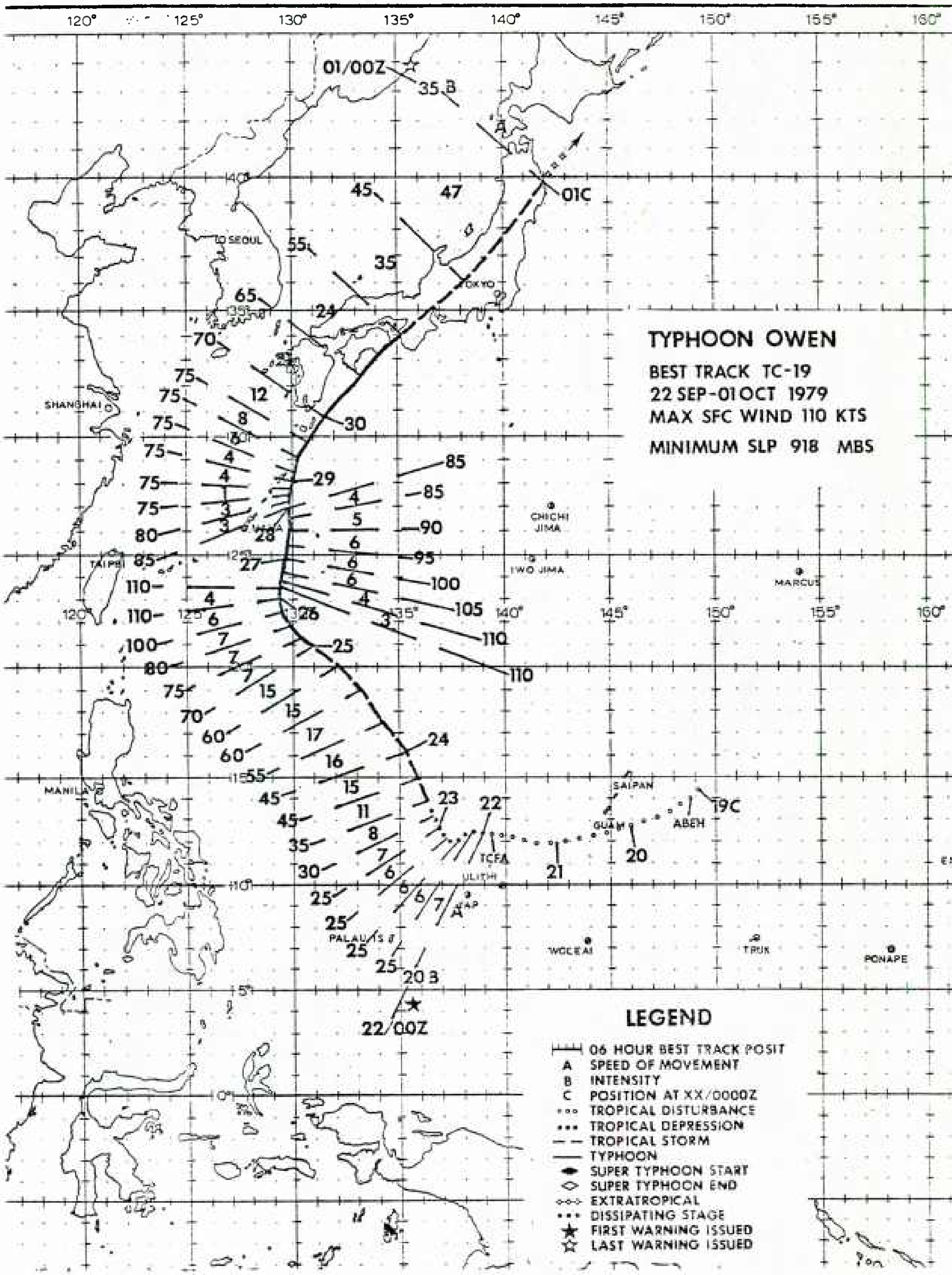


Figure 1. Surface best track for Typhoon Owen (September-October, 1979)

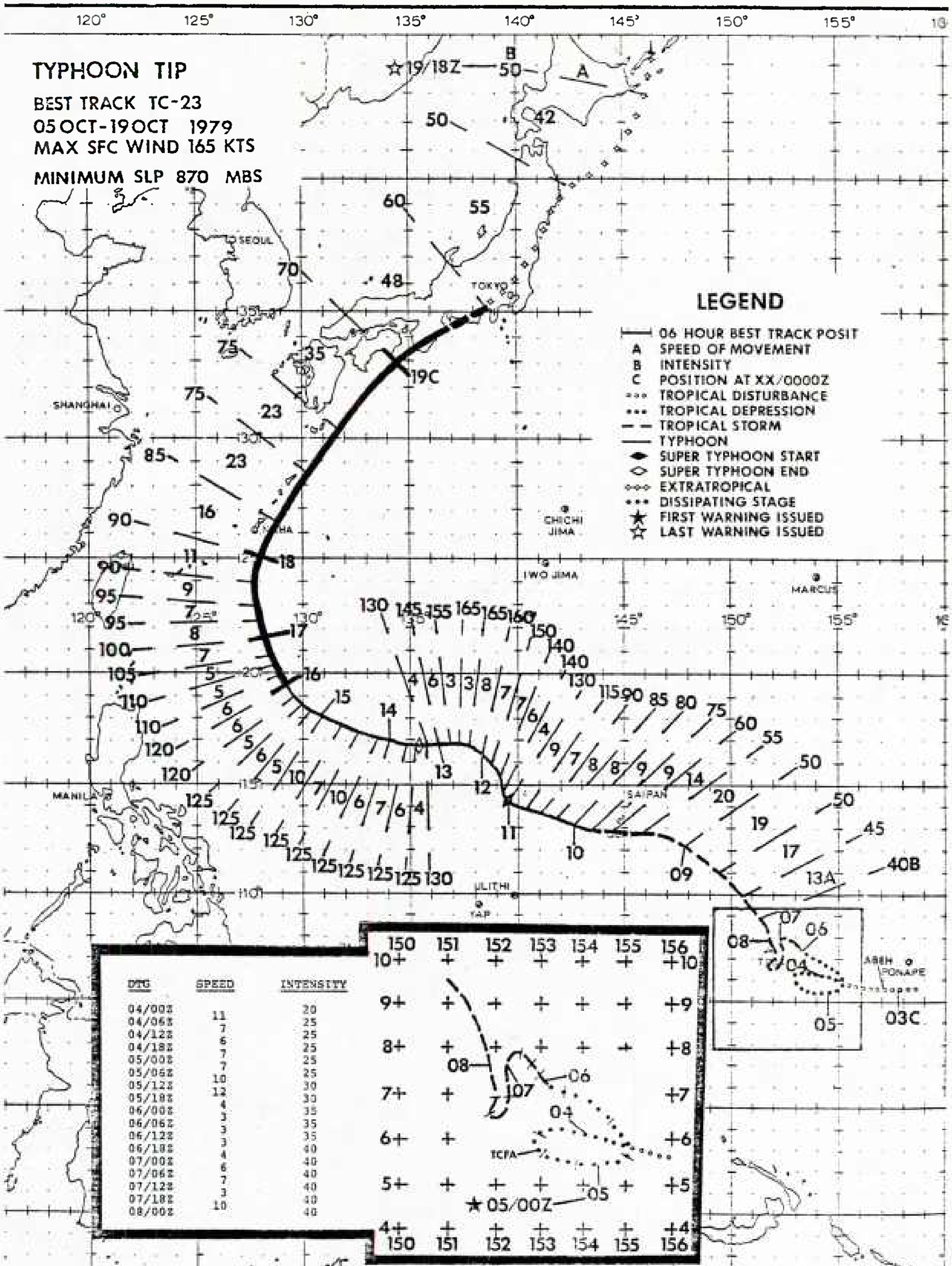


Figure 2. Surface best track for Typhoon Tip (October, 1979)

TABLE 2. SPEED OF MOVEMENT FORECASTS AND VERIFICATIONS FOR TYPHOON TIP (OCTOBER, 1979).

WRNG Nr	WRNG Valid Time	12-hr Speed to Wrng Pt	24-HOUR Speed of Movement (kt) Fcst	24-HOUR Speed of Movement (kt) Actual	24-HOUR Timing Error (hr)	48-HOUR Speed of Movement (kt) Fcst	48-HOUR Speed of Movement (kt) Actual	48-HOUR Timing Error (hr)	72-HOUR Speed of Movement (kt) Fcst	72-HOUR Speed of Movement (kt) Actual	72-HOUR Timing Error (hr)
45	16/00Z	6	6	6	+ 1	6	9	- 8	5	24	-26
46	16/06Z	6	4	7	-10	6	10	-16	6	32	-31
47	16/12Z	6	6	7	- 2	7	14	-12	7	40	-33
48	16/18Z	5	6	8	- 4	7	18	-16	8	47	-32
49	17/00Z	6	6	9	- 7	7	24	-20	8	48*	-36
50	17/06Z	7	7	10	- 9	8	32	-22	9	--	-38
51	17/12Z	7	7	14	-10	8	40	-25	16	--	-37
52	17/18Z	8	8	21	-13	9	47	-28	19	--	-38
53	18/00Z	10	11	24	-12	15	48*	-24	20	--	-39
54	18/06Z	14	15	32	-10	25	--	-22			
55	18/12Z	20	23	40	- 8						
56	18/18Z	23	27	47	-10						
57	19/00Z	29	33	48*	- 7						
45 to 50					- 5			-16			-33
51 to 57					-10			-25			-38
45 to 57					- 8			-19			-35

* 18-hour (vice 24-hour) speed of movement (190000Z to 191800Z)

This table verifies warnings 45 through 57 for speed of movement and presents resultant timing errors. Warnings 45 to 50 were issued prior to acceleration; warnings 51 to 57 were issued during acceleration. During the latter sequence, acceleration was forecast but not to the degree that actually occurred.

NOTE: Timing errors are determined by dividing the distance from the forecast position to the verifying best track position by the actual speed of movement for the respective 24-hour period. A negative (-) timing error indicates that the JTWC forecast was too slow.

III. DATA AND METHODOLOGY

The frequency of occurrence of the acceleration phenomenon, and other statistical data which could be correlated with the acceleration of typhoons[1], was obtained by screening the Annual Typhoon Reports (1971-1979) and Annual Tropical Cyclone Reports (1980-1981). Drawing from the population of typhoons that traversed the relatively high-density data area south of Japan, 58 typhoons were selected for further study; Appendix A provides a summary of the data collected and the results of the study. In summary, these correlations were evident:

* Acceleration was a very common event for those northward-moving typhoons: eighty-eight percent of those studied underwent significant increases in their speeds of movement while entering the mid-latitudes.

* There was a tendency for the "accelerating" typhoons to <u>triple</u> their speeds of movement within the first 36 hours of the acceleration period.

* There was a month-to-month variation, an apparent climatology, in the <u>mean</u> latitudes where these accelerations took place.

The 200 mb chart was selected as a means to investigate relationships between tropical cyclone accelerations and the mid-latitude westerlies because of the availability of a wide range of reliable upper-tropospheric wind data (i.e. rawinsonde and aircraft reports, and cloud motion vectors) over the mid-latitudes of the western North Pacific. As a test case, JTWC's 200 mb hand-plotted charts (0000Z/1200Z data base) were reanalyzed and then examined for the seven northward-moving typhoons of 1981. From a time period from 48 hours prior, to 24 hours after the onset of acceleration, each 200 mb chart was inspected for evidence of meteorological factors common to each acceleration. Factors that were considered in this process included the presence and relative location of nearby mid-latitude troughs and ridges, upper-tropospheric streamline configurations (wind flow patterns), and distance between the tropical cyclone and the southern periphery of the mid-latitude westerlies. Features which were common in the six accelerating cases were compared with the analyses for Typhoon Agnes, which did not accelerate into the mid-latitudes.

Overlaying the various individual analyses for the specific time periods mentioned above produced a composite 200 mb streamline pattern (Figure 3) which could then be compared to each chart analysis to determine what relationships, if any, were <u>closely</u>

[1] Typhoons were selected for this study because the Annual Typhoon Reports, prior to 1979, contained considerably less documentation on tropical cyclones which did not attain typhoon status.

related to the acceleration process. The following relationships, in order of their effect on the accelerations, were deduced:

* Acceleration began when the tropical cyclone moved within five to seven degrees of the 30 kt (15 m/sec) isotach associated with the mid-latitude westerlies.

* The presence of a relatively strong (> 25 kt (13 m/sec)) northerly flow west of the tropical cyclone was associated with slower initial speeds during the acceleration process.

* The more southerly the component of the mid-latitude westerlies, the closer the tropical cyclone moved toward the westerlies before the acceleration began.

* The more northerly the component of the mid-latitude westerlies, the greater the effect of vertical wind shear on the tropical cyclone and the less the likelihood of a significant and/or sustained acceleration.

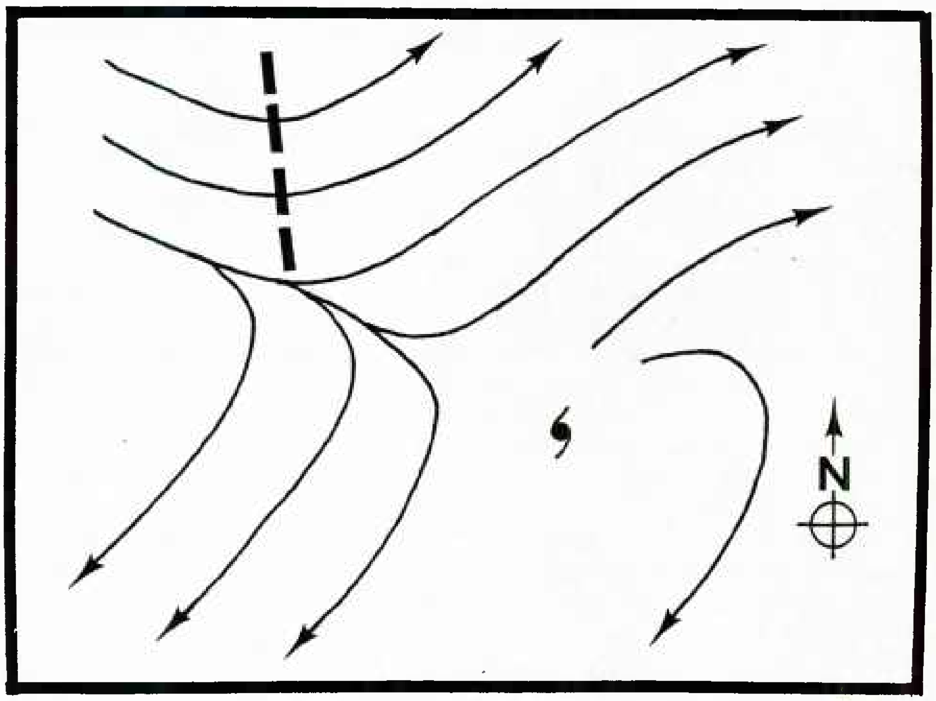


Figure 3. A composite 200 mb analysis which was constructed from analyses approximately 12 hours prior to the onset of acceleration of five 1981 typhoons (June, Thad, Bill, Elsie and Gay). Note the approximate distance from the typhoon center to the westerlies (eight degrees latitude) and the presence of a northerly wind flow to the west of the typhoon center.

IV. TECHNIQUE DEVELOPMENT

Given the historical evidence of northward-moving tropical cyclones accelerating, plus the inferred relationships between the upper-tropospheric wind flow and accelerating tropical cyclones, the next step was to develop a viable technique to assist in forecasting these accelerations. However, since the technique would be used only in those instances when a tropical cyclone is moving, or is expected to move, northward into the mid-latitudes, there would be a high percentage of forecast situations that would not require its usage. To encourage the use of the acceleration technique it must therefore be relatively simple in design and application, and be readily adaptable to the existing JTWC forecast development routine.

Use of an overlay, to be placed directly on the most-recent 200 mb chart, was the most promising of the various techniques examined. The success of the composite 200 mb analysis (Figure 3) in identifying certain upper-tropospheric wind flow patterns, and their locations relative to tropical cyclones prior to the onset of acceleration, led to its incorporation into the configuration of the initial overlay pattern (Figure 4). The final overlay pattern (Figure 5) is merely a simplification of the initial design.

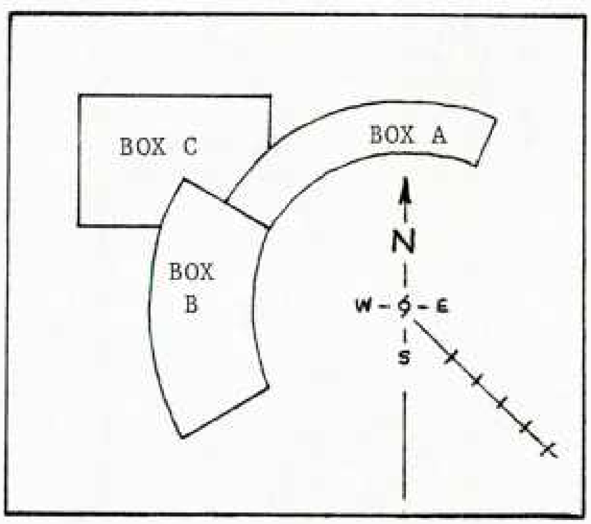


Figure 4. TAPT overlay which was used during the 1982 tropical cyclone season.

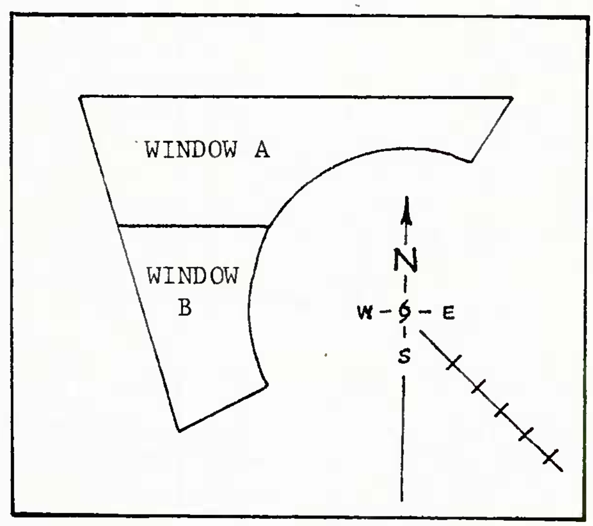


Figure 5. Simplified TAPT overlay.

The latitude where acceleration should begin is determined by applying the overlay to the 200 mb data; however, there is another important consideration, which is the rate of the subsequent acceleration. The overlay can identify a specific upper-tropospheric wind pattern, west of the tropical cyclone, which has been correlated with a slightly delayed or slower initial rate of acceleration. From this initial acceleration period, it then becomes important to forecast the speed of movement throughout the acceleration period. From the study of northward-moving typhoons (Appendix A), it was noted that most of those accelerations could have been approximated by multiplying the speed of movement by 1.25 at six-hour intervals until the acceleration had been completed. When tested against 1981's accelerating typhoons, this approximation scheme worked quite well (timing errors were less than two hours for any best track position during each of the acceleration periods); thus, this speed of movement approximation scheme was introduced into the operational technique prior to the first northward-moving tropical cyclone event of the 1982 season. This operational technique thus employed a 200 mb chart overlay and a set of acceleration tables (one for "typical" and one for "more rapid" speeds of movement during acceleration). When applied to the JTWC 200 mb chart, this technique seemed to satisfy the requirement for a viable, simple to use tool to assist the forecaster in predicting the acceleration of tropical cyclones into the mid-latitudes.

As the 1982 tropical cyclone season began in the western North Pacific, one area remained unresolved: what effect would the mean direction of the westerly flow, near the tropical cyclone, have on the duration and/or upper-limits of the acceleration? Although JTWC had a two-year data set (1980-1981) of manually analyzed 200 mb charts to correlate upper-tropospheric wind patterns to tropical cyclone movement, only those for the latter part of 1981 had a sufficient amount of upper wind data, south of 30N and east of 140E, to adequately represent these upper-tropospheric wind patterns. (In late September, 1981, JTWC began to routinely plot satellite-derived cloud motion vectors (winds) on its 200 mb charts. The inclusion of these data greatly expanded the credibility and utility of the analyses at this atmospheric level). During 1980 and 1981, 25 tropical cyclones moved northward into the mid-latitudes; however, when the criterion for an adequate number of nearby upper-tropospheric wind reports was introduced, the number of cases were reduced considerably. This meant that most of the acceptable cases, for these years, were associated with tropical cyclones that accelerated with a predominately southwesterly flow to the west and northwest of their positions. Lacking a sufficient number of cases where the flow came from a direction other than the southwest, guidelines for duration and upper-limits were not included with the initial operational technique.

Midway through 1982, it became apparent that the more northerly the upper-tropospheric wind flow, the shorter the period of the acceleration, if any. Thus, westerly flow tended to produce accelerations about two-thirds to one-half of the duration and final speed of that associated with southwesterly flow. Based upon the tracks of Typhoons Pat and Ruby, Tropical Storms Skip and Val of 1982, and the upper-tropospheric winds associated with them and the accelerating tropical cyclones of 1980 and 1981, a set of pattern recognition diagrams and guidelines were introduced into the technique. By September, another modification was added, which included combining the numerical prognostic fields with the manual analysis to determine the most probable upper-tropospheric wind pattern which would prevail during the acceleration period.

The intent to develop a technique which could capitalize on the relative abundance of upper-tropospheric wind data over the mid-latitudes of the western North Pacific had influenced virtually every technique-development decision throughout the 1982 tropical cyclone season. Although utilizing upper-tropospheric wind data had proven to be quite effective in most forecast situations, it became apparent during the season, that in certain situations the counter-effect of a well-established low-level easterly steering current would impede the anticipated acceleration. After the conclusion of the 1982 tropical cyclone season the final modification to the technique was made, which included a check on the strength of the low-level steering near the tropical cyclone and an additional acceleration table for those cases when the low-level steering can be expected to delay the onset of the most significant speeds of movement during acceleration.

The final operational technique, Appendix B, is representative of the technique which evolved during the 1982 season. The introduction of pattern recognition and guidelines for the duration and upper-limits of acceleration did not affect the identification of the most probable latitude for the onset of the acceleration process. Therefore in the next section, that aspect of the technique will be stressed above the other acceleration estimates in evaluating the technique's effectiveness during the 1982 tropical cyclone season.

V. Results

The intent of the Typhoon Acceleration Prediction Technique (TAPT) was to provide the forecaster with a means of estimating the influence of the mid-latitude, upper-tropospheric westerlies on the movement of a tropical cyclone entering the domain of the westerlies. TAPT was not designed to produce a set of forecast positions for specified valid times, therefore forecast errors could not be tabulated and compared to the positions from the JTWC warning or other objective techniques. In order to

evaluate TAPT's performance during the 1982 tropical cyclone season, it was necessary to focus attention on the accuracy and reliability of its estimates of the latitude where these accelerations were to begin. TAPT's estimates of the rate of acceleration, the duration of the acceleration period, the upper-limit of the speed of movement during acceleration and the basic track of the accelerating tropical cyclone were being developed and refined throughout most of the 1982 tropical cyclone season, Although these latter estimates were also evaluated, it must be emphasized that they were not derived from a real-time evaluation as the estimates of latitude were.

Appendix C provides the results of TAPT's performance during the 1982 tropical cyclone season. In summary, TAPT's estimates of the latitude where these accelerations began were quite good, and in virtually every acceleration event, its estimate of the latitude could be extracted from the 200 mb data as early as 36 to 48 hours prior to the beginning of the acceleration process. The exception to this was Typhoon Gordon (16) in September; Gordon's northward movement occurred during a period of rapid changes in the north-south orientation of the mid-latitude westerlies -- TAPT's estimates of latitude fluctuated during this period as the westerlies changed. The remaining elements of the technique, i.e. acceleration rates, duration and upper-limits of the acceleration, and the basic track during acceleration, were more than adequate during most of these acceleration events. When these latter estimates were derived from the final operational technique (Appendix B), they were quite good and, in most cases, showed promise of providing estimates that will be as good as the latitude where acceleration should begin.

VI. Summary

This technical report has provided an overview of some of the research into the phenomenon of tropical cyclones accelerating as they enter the domain of the mid-latitude westerlies. Some of the problems associated with actually forecasting these accelerations have been discussed along with the long-standing need for an operational technique to assist in forecasting these accelerations. The study of 58 northward-moving typhoons from an 11-year data base (Appendix A) provided a great deal of insight into the historical behavior and frequency of these accelerations. That study, along with the 200 mb chart analyses of 1981's accelerating tropical cyclones, served as the framework for the development of an operational technique (Typhoon Acceleration Prediction Technique (TAPT)). TAPT was incorporated into the JTWC forecast development process during the 1982 tropical cyclone season and as the season progressed, some refinements were made to the technique. The resultant technique (Appendix B) has been tested against the northward-moving tropical cyclones of 1982 (Appendix C). TAPT's

performance during the 1982 tropical cyclone season was quite encouraging.

The desired simplicity of an operational technique has been realized with TAPT. However, by relying primarily on the upper-tropospheric (200 mb) wind fields for input, TAPT estimates are very dependent on this atmospheric level being representative of the troposphere, from the upper- to lower-levels. Thus, even the check on nearby low-level steering currents (used for determination of the rate of acceleration) is a simplification of what is an extremely complex and dynamic meteorological problem. In lieu of a responsive state-of-the-art dynamic technique to handle these acceleration events, TAPT should serve its intended purpose and aid in the development of reasonable forecasts as tropical cyclones approach the mid-latitudes.

Although TAPT was developed for use in the western North Pacific Ocean, it may serve as a useful tool in forecasting the acceleration of tropical cyclones in the North Atlantic Ocean. Xu and Gray (1982) indicated similar synoptic-scale wind flow patterns were associated with the rapid movement of tropical cyclones as they moved north of the subtropical ridge axis for both oceanic regions. Figure 6, extracted from their report, indicates that a nearly equal percentage of tropical cyclones moved rapidly (>14 kt (27 km/hr)) in both oceans, north of 10N. The acceleration phenomenon is less common in other oceanic regions, i.e. eastern North Pacific, South Pacific, Australian area, North Indian, and South Indian, due, in part, to a more equatorward displacement of the mid-latitude westerlies, which tends to shear, vice accelerate a poleward-moving tropical cyclone. (This feature plays a limited role in the North Indian Ocean, where tropical cyclones are also weakening due to interaction with landmasses.)

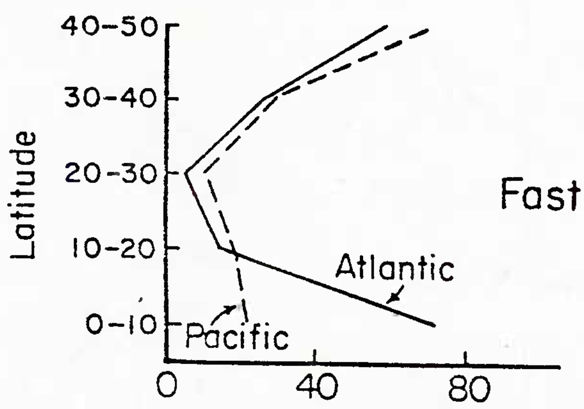


Figure 6. Percentage of tropical cyclones in the Atlantic and western North Pacific which are fast (> 14 kt (27 km/hr)).

(From Xu and Gray, 1982)

ACKNOWLEDGEMENTS

The author is indebted to Lieutenant Colonel Dean A. Morss, USAF, for his constructive suggestions during the preparation of this manuscript. The entire forecasting staff of the Joint Typhoon Warning Center (JTWC) deserves special recognition for their willingness to incorporate the Typhoon Acceleration Prediction Technique (TAPT) into the JTWC forecast development routine; thus giving the technique an opportunity to be utilized and evaluated over the entire 1982 tropical cyclone season for the western North Pacific. A special thanks to James A. Sadler, Department of Meteorology, University of Hawaii, and William M. Gray, Department of Atmospheric Sciences, Colorado State University, who spent many hours with the author discussing the acceleration phenomenon; their encouragement and insight into this phenomenon is most gratefully appreciated. Finally, the author wishes to thank Aerographers Mate Second Class James A. Frush, USN, for his graphics support and Mrs. Cynthia Blevins for the typing of the manuscript.

APPENDIX A

STUDY OF NORTHWARD-MOVING TROPICAL CYCLONES SOUTH OF JAPAN (1971-1981)

Survey Area: From 122E (near the coast of Asia) to 147E, north of 20N (Figure A-1).

Case Eligibility: Any tropical cyclone that had been designated a "typhoon" during its life span and tracked into the survey area, then assumed a heading to the right (or clockwise) of 325 degrees true and reached 30N was included in the evaluation for the 11-year period 1971-1981.

Results: From the above screening criteria, 58 typhoons were evaluated (Table A-1). Of these, 42 (72%) attained at least 19 kt (35 km/hr) prior to reaching their final best track[1] positions. Further screening of these 42 typhoons revealed that 26 (62%) attained at least 27 kt (50 km/hr) and 10 (24%) attained at least 38 kt (70 km/hr). Of the remaining 16 typhoons: nine doubled their pre-acceleration speeds of movement but did not reach the 19 kt (35 km/hr) threshold; three failed to double their pre-acceleration speeds but nonetheless increased their speeds of movement; and only four showed no tendency to increase their speeds of movement during their mid-latitude best track periods. There were 26 typhoons which increased their speeds of movement to 25 kt (45 km/hr) or more; however, only two (Rita, 1972 and Babe, 1977) were not associated with recurving or nearly recurving[2] best tracks. For the 58 typhoons evaluated, 51 (88%) either attained 19 kt (35 km/hr) or at least doubled their speeds of movement while approaching Japan from the south.

1 Determination of best track positions is accomplished in post-analysis by re-evaluating all available data. The resulting best track is often a relatively smooth track constructed from positions at six-hour intervals and may not fully represent the precise movement of a tropical cyclone. The best track process is partially subjective and there may be some differences from year-to-year and between individual analysts on the final product. However, the overall tendency of tropical cyclone movement, especially significant increase in speed of movement, is generally well described by the best track positions.

2 The Glossary of Meteorology (AMS, 1959) states "*recurvature is the change in direction from westward and poleward to eastward and poleward*". That definition is accepted for recurving tropical cyclones; however, there is another set of tropical cyclones (occurring chiefly in July, August and early September) which may not complete their recurvatures until well after they have undergone extratropical transition or some other process which terminates their best tracks. These tropical cyclones are referred to as *nearly recurving* in this study.

The average time for the 42 tropical cyclones to reach the threshold of 19 kt (35 km/hr) was 25 hours from a mean pre-acceleration speed of 9 kt (17 km/hr). When all 51 "accelerating" tropical cyclones are analyzed, the average time from a pre-acceleration speed of 8 to 9 kt (15 to 17 km/hr) to a final mean maximum speed of 28 kt (52 km/hr) was 34 hours. These results suggest a tendency for most northward-moving (accelerating) tropical cyclones to triple their speeds of movement within the first 36 hours of the acceleration period.

On the average these accelerations began near 27N and were completed prior to 33N (Tokyo is located near 35.6N). All but three tropical cyclones began their accelerations south of 32N. There appears to be a sufficient number of cases to indicate a tendency for tropical cyclones, on a month-by-month basis, to begin their accelerations within a few degrees of one or, in some months, two identifiable latitudes.

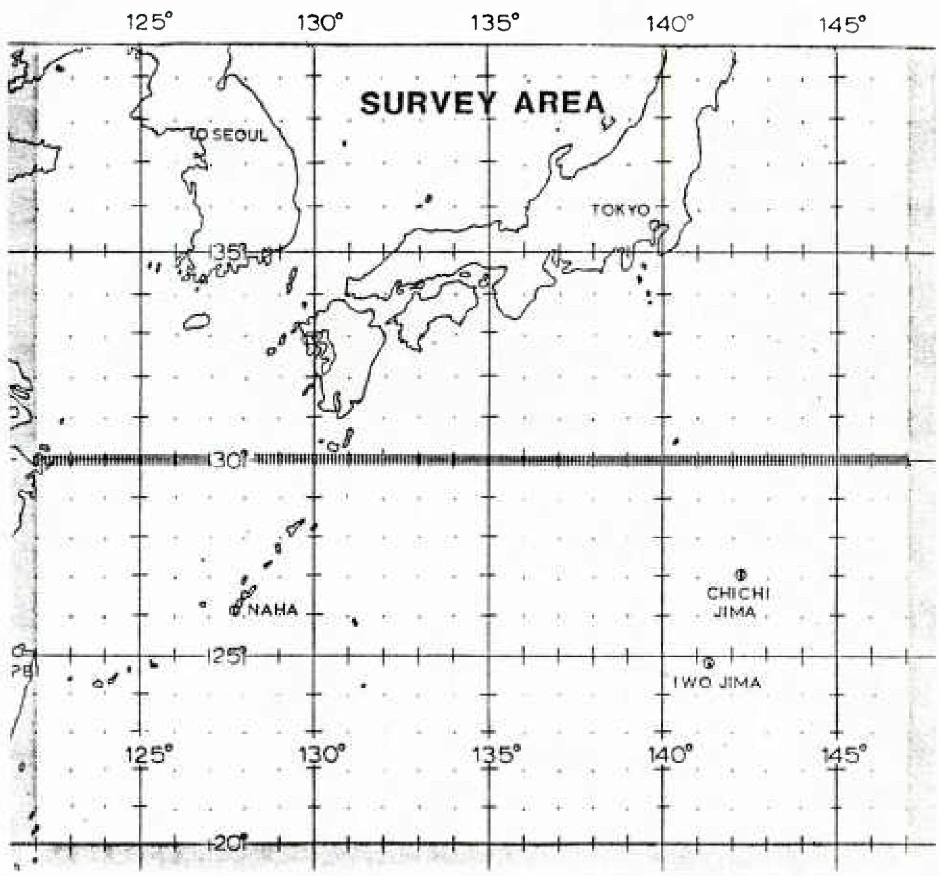


Figure A-1. Survey area south of Japan where the best tracks of typhoons were analyzed to verify the acceleration phenomenon. Not only does this area represent the region most tropical cyclones traverse before threatening the main islands of Japan, it also contains the highest density of upper-level wind data which can be analyzed for correlation with tropical cyclone movement.

TABLE A-1. NORTHWARD-MOVING TROPICAL CYCLONES, SOUTH OF JAPAN (1971-1981)

	EVENT 1			EVENT 2			EVENT 3			EVENT 4			
	PRE-ACCELERATION DATA			FIRST DOUBLING OF PRE-ACCEL SPEED			MAXIMUM SPEED IN ACCELERATION			BEST TRACK TERMINATION DATA			
YEAR TYPHOON	Date	Speed	Latitude	Speed	Latitude	Elapsed Time Event 1 to 2	Speed	Latitude	Elapsed Time Event 1 to 3	Latitude	Elapsed Time Event 1 to 4	Reason	Intensity
1971													
VERA	17 APR	9k	21.4N	18k	25.2N	18h	←-	-----	---	26.1N	30h	Extratropical	35k
OLIVE	03 AUG	5k	28.9N	13k	31.1N	18h	20k	39.4N	36h	←---	---	Extratropical	50k
SHIRLEY	14 AUG	5k	24.1N	10k	26.9N	24h	40k	41.6N	66h	←---	---	Extratropical	90k
TRIX	29 AUG	6k	29.6N	12k	33.1N	24h	14k	34.2N	36h	←---	---	Extratropical	40k
VIRGINIA	06 SEP	6k	24.9N	13k	31.1N	18h	16k	33.8N	30h	←---	---	Extratropical	70k
IRMA	13 NOV	8k	22.3N	17k	26.4N	24h	35k	30.7N	42h	←---	---	Extratropical	65k
1972													
PHYLLIS	15 JUL	11k	31.5N	---	-----	---	21k	33.5N	6h	35.1N	12h	Dissipated	40k
RITA	25 JUL	9k	29.3N	28k	34.7N	18h	30k	37.1N	30h	38.3N	30h	Dissipated	55k
TESS	22 JUL	10k	29.4N	28k	37.0N	42h	←-	-----	---	←---	---	Dissipated	45k
ALICE	06 AUG	11k	32.8N	---	-----	---	19k	40.3N	36h	←---	---	Extratropical	40k
HELEN	15 SEP	11k	22.1N	24k	29.3N	24h	29k	31.9N	30h	34.4N	36h	Extratropical	65k
IDA	22 SEP	8k	21.6N	20k	23.3N	12h	26k	36.2N	30h	38.0N	36h	Extratropical	60k
MARIE	10 OCT	7k	20.6N	14k	24.0N	18h	34k	35.0N	48h	←---	---	Extratropical	60k
OLGA	28 OCT	13k	23.0N	27k	27.3N	12h	36k	33.0N	24h	←---	---	Extratropical	75k
1973													
BILLIE	17 JUL	7k	28.3N	14k	31.5N	18h	←-	-----	---	35.9N	48h	Extratropical	50k
DOT	19 JUL	9k	28.4N	18k	32.6N	24h	23k	34.8N	24h	←---	---	Dissipated	25k
ELLEN	18 JUL	3k	22.8N	7k	23.5N	6h	13k	28.2N	24h	34.6N	144h	Dissipate/Loop	25k
IRIS	16 AUG	9k	31.0N	20k	37.3N	24h	22k	39.3N	30h	←---	---	Extratropical	30k
1974													
GILDA	05 JUL	8k	27.6N	18k	34.7N	42h	19k	36.3N	48h	←---	---	Extratropical	40k
MARY	24 AUG	13k	26.1N	26k	34.5N	30h	34k	37.5N	36h	←---	---	Extratropical	25k
POLLY	01 SEP	7k	32.5N	15k	34.0N	6h	21k	36.0N	12h	37.7N	18h	Extratropical	45k
SHIRLEY	07 SEP	4k	29.2N	7k	29.8N	6h	24k	33.7N	30h	←---	---	Extratropical	35k
1975													
PHYLLIS	16 AUG	7k	30.2N	14k	33.9N	24h	←-	-----	---	37.5N	54h	Extratropical	25k
RITA	21 AUG	7k	30.0N	14k	34.3N	24h	38k	40.0N	42h	41.7N	48h	Extratropical	30k
TESS	08 SEP	6k	30.3N	12k	32.2N	12h	25k	35.3N	24h	40.0N	36h	Extratropical	45k
CORA	03 OCT	9k	23.7N	19k	30.3N	30h	35k	35.2N	54h	←---	---	Extratropical	100k
JUNE	22 NOV	11k	21.7N	29k	27.2N	24h	42k	29.9N	30h	←---	---	Extratropical	80k
1976													
PAMELA	25 MAY	8k	26.3N	---	-----	---	15k	28.4N	18h	←---	---	Extratropical	50k
RUBY	01 JUL	10k	22.9N	20k	28.2N	36h	24k	30.8N	48h	33.2N	60h	Extratropical	60k
SALLY	29 JUN	8k	22.5N	17k	26.9N	30h	33k	34.5N	72h	←---	---	Extratropical	40k
THERESE	Mid JUL	---	-----	---	-----	---	---	-----	---	32.2N	---	Dissipate/Loop	20k
ANITA	23 JUL	e14k	19.5N	---	-----	---	21k	26.9N	24h	33.6N	48h	Extratropical	25k
FRAN	12 SEP	4k	30.4N	9k	33.3N	12h	22k	37.0N	30h	←---	---	Extratropical	40k
LOUISE	05 NOV	9k	21.5N	18k	25.9N	24h	23k	30.6N	48h	←---	---	Extratropical	55k

	EVENT 1			EVENT 2			EVENT 3			EVENT 4			
	PRE-ACCELERATION DATA			FIRST DOUBLING OF PRE-ACCEL SPEED			MAXIMUM SPEED IN ACCELERATION			BEST TRACK TERMINATION DATA			
YEAR TYPHOON	Date	Speed	Latitude	Speed	Latitude	Elapsed Time Event 1 to 2	Speed	Latitude	Elapsed Time Event 1 to 3	Latitude	Elapsed Time Event 1 to 4	Reason	Intensity
1977													
BABE	08 SEP	8k	21.9N	16k	25.0N	18h	28k	30.7N	36h	31.5N	54h	Dissipated	70k
1978													
VIRGINIA	01 AUG	9k	33.6N	18k	39.1N	24h	←-	-----	---	41.8N	48h	Extratropical	35k
WENDY	02 AUG	7k	31.2N	17k	33.5N	12h	←-	-----	---	34.6N	18h	Extratropical	35k
CARMEN	18 AUG	6k	28.1N	14k	31.4N	24h	19k	34.8N	36h	←---	---	Extratropical	30k
FAYE	early SEP	---	-----	---	-----	---	---	-----	---	30.6N	---	Extratropical	35k
IRMA	14 SEP	10k	31.5N	21k	34.2N	18h	←-	-----	---	34.7N	30h	Dissipated	30k
JUDY	15 SEP	5k	29.8N	11k	32.4N	18h	31k	42.0N	54h	←---	---	Extratropical	40k
1979													
IRVING	15 AUG	7k	27.5N	15k	31.7N	24h	30k	39.5N	42h	←---	---	Extratropical	25k
JUDY	25 AUG	6k	30.9N	13k	33.9N	30h	←-	-----	---	←---	---	Extratropical	25k
LOLA	07 SEP	8k	30.8N	---	-----	---	15k	34.4N	18h	←---	---	Extratropical	40k
OWEN	29 SEP	4k	28.5N	8k	29.8N	12h	47k	39.8N	42h	←---	---	Extratropical	35k
TIP	17 OCT	7k	23.0N	16k	26.5N	18h	48k	36.2N	42h	←---	---	Extratropical	60k
1980													
ELLEN	20 MAY	16k	25.6N	34k	34.3N	24h	←-	-----	---	←---	---	Extratropical	35k
ORCHID	11 SEP	16k	31.4N	35k	37.3N	12h	←-	-----	---	←---	---	Extratropical	40k
SPERRY	mid SEP	---	-----	---	-----	---	---	-----	---	34.3N	---	Extratropical	30k
WYNNE	12 OCT	7k	26.1N	15k	29.8N	24h	44k	35.5N	54h	←---	---	Extratropical	60k
BETTY	06 NOV	7k	19.9N	14k	22.4N	18h	23k	25.6N	36h	←---	---	Extratropical	35k
1981													
JUNE	20 JUN	12k	29.7N	---	-----	---	19k	32.6N	18h	←---	---	Extratropical	30k
OGDEN	29 JUL	13k	29.3N	---	-----	---	18k	30.8N	12h	36.0N	54h	Dissipated	25k
THAD	21 AUG	5k	29.6N	10k	31.0N	12h	45k	41.9N	36h	46.8N	42h	Extratropical	45k
AGNES	AUG-SEP	---	-----	---	-----	---	---	-----	---	31.8N	---	Extratropical	60k
BILL	05 SEP	11k	29.4N	26k	36.6N	24h	42k	40.5N	36h	←---	---	Extratropical	40k
ELSIE	30 SEP	10k	25.3N	24k	30.2N	24h	45k	35.9N	42h	←---	---	Extratropical	55k
GAY	21 OCT	10k	25.6N	22k	29.3N	18h	43k	36.6N	36h	←---	---	Extratropical	65k

APPENDIX B

TYPHOON ACCELERATION PREDICTION TECHNIQUE (TAPT)

The purpose of this technique is to provide tropical cyclone forecasters with a real-time synoptic prediction technique for determining where and/or if a northward-moving tropical cyclone will undergo a significant increase in speed of movement as it approaches the domain of the mid-latitude westerlies.

This technique will assist in the identification of specific flow patterns at the upper-tropospheric (mean 200 mb) level which have been associated with the acceleration[1] of previous tropical cyclones. It will further provide guidance to assist in identifying those northward-moving tropical cyclones which should not experience significant accelerations.

The application of the technique requires the use of the most-recent 200 mb data and the 200 mb (numerical) prognostic series that covers the next 24- to 48-hour period. The essence of the technique is the identification of the domain of the mid-latitude westerlies. The forecaster must carefully review all of the 200 mb wind data prior to conducting the TAPT evaluation; raw data, i.e. rawinsonde/pibal winds, AIREPs and cloud motion winds, are preferred over numerically smoothed analysis winds. Once the determination has been made that there is a sufficient amount of raw data available to conduct the evaluation, the technique will provide:

- a YES/NO decision for a significant increase in the speed of movement;
- a "best" location (latitude) for the initiation of the acceleration process;
- speed of movement guidelines including duration and upper-limits;
- insight on the probable path of the tropical cyclone.

NOTE: It is imperative that the forecaster closely evaluate the applicability of the TAPT conclusions each time the technique is attempted. The validity of the results is highly dependent

[1] Acceleration is a term that will be used with this technique to describe tropical cyclone movement over a sustained period where there is forecast to be a significant increase in speed -- implying that an acceleration process will be in effect over the total time period. Due to tropical cyclone fix limitations or best tracking techniques, the overall acceleration may not be evident at each six-hour time interval.

on: the 200 mb chart containing a sufficient amount of data to depict the southern extremity of the mid-latitude westerlies; the wind data present on the 200 mb chart being representative of a deeply penetrating layer of mid-latitude westerlies, i.e. 200-700 mb stratum; and the tropical cyclone maintaining a northward movement and being in position to be affected by the mid-latitude westerlies. The following environmental factors have also been observed to affect the subsequent acceleration of the tropical cyclone and may be at variance with the TAPT forecast:

(1). A strong northerly or easterly low-level flow that will impede tropical cyclone movement. Normally, when this effect occurs early in the predicted acceleration period, the tropical cyclone will drift northward for one to two degrees latitude before the acceleration commences. If it occurs later in the acceleration period, it often marks the end of the acceleration process. Thus, a check on low-level steering will be necessary prior to applying this technique.

(2). A poorly-defined or very small mid- or upper-level circulation center which does not (directly) link the tropical cyclone's low-level center to the mid-latitude westerlies. In such cases, the relative strength of the low-level steering should be more representative of the tropical cyclone's movement.

(3). A well-defined tropical upper-tropospheric trough (TUTT) lying between the tropical cyclone and the mid-latitude westerlies. Interaction with the TUTT will often slow a tropical cyclone and alter its upper-level circulation pattern, causing it to respond to steering influences at lower levels.

Instructions:

STEP

1. Locate the position of the tropical cyclone at the valid-time of the 200 mb chart. Annotate this position with a "⊠". From 15 to 20 degrees longitude west of the tropical cyclone, locate the southern extremity of the mid-latitude westerlies by sketching the 30 kt isotach eastward to the longitude of the tropical cyclone. Be careful not to drop the isotach into the flow originating from the tropical latitudes (see Figure B-1).

2. Place the overlay (Figure B-8) on the 200 mb chart with the "large-scale" TAPT diagram's "6" above the chart's "⊠" symbol. Orient the overlay to true north and maintain this orientation throughout the evaluation. Use the "small-scale" diagram with the numerical prognostic charts.

3. With the TAPT overlay in place, average the wind speeds present in Window A. If the average wind speed is less than 30 kt, continue the evaluation by moving the TAPT overlay northwestward while maintaining the chart's "⊠" symbol under the overlay's baseline.

4. STOP the evaluation when the average wind speed is 30 kt or greater in Window A (Go to step 5), or when the "⊠" symbol is located beyond the "arrow" at the end of the baseline. If the evaluation has been stopped at the end of the baseline and if a prolonged northward track is still likely, go to the Climatology Section (p. 31) to estimate the latitude where acceleration may begin.

5. If the evaluation has been stopped with 30 kt or greater in Window A, then the following instructions will identify the potential for acceleration. TO OBTAIN THE "BEST LATITUDE" FOR SIGNIFICANT ACCELERATION TO BEGIN, THE PATTERN OF THE UPPER-TROPOSPHERIC, MID-LATITUDE WESTERLIES MUST BE IDENTIFIED NEXT.

6. If the overlay's "6" symbol is within two degrees of the chart's "⊠" position, then the current analysis chart and the 24-hour prognostic chart should be used to determine the upper-tropospheric wind pattern that will prevail during acceleration. Evaluate any differences between the wind pattern shown in the analysis and the prognotic chart before deciding on the future upper-tropospheric wind pattern.

7. If the overlay's "6" symbol is greater than two degrees from the chart's "⊠" position, then refer to the numerical prognostic charts with valid-times closest to the forecast arrival of the tropical cyclone at the latitude shown under the "6" symbol to determine the upper-tropospheric wind pattern that should prevail during the acceleration.

8. From the figures (B-2 through B-6) that follow, identify the upper-tropospheric wind pattern that best suits the pattern determined in Step 7 or 8. Follow the instructions given for the selected figure. When completed, review the Discussion Section before applying the technique (TAPT) to the forecast.

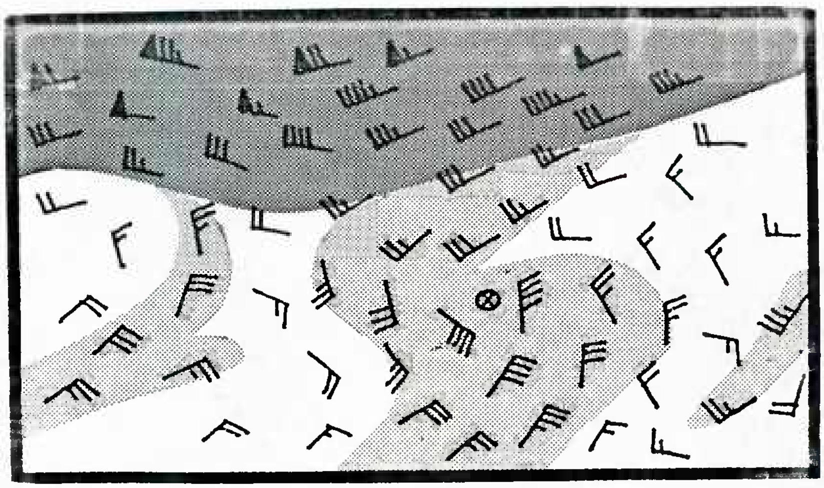
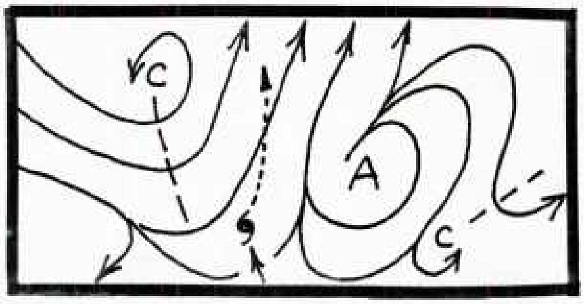


Figure B-1. Shaded areas indicate winds ≥ 25 kt. Dark gray shading indicates the domain of the mid-latitude westerlies; light gray shading shows the areas of strong upper-tropospheric winds outside of the mid-latitudes. These light gray areas are normally associated with upper-tropospheric currents whereas, in the dark gray area, the westerlies normally penetrate into the mid- and lower-tropospheric levels. It is this deeply penetrating current of mid-latitude westerlies which tends to draw the tropical cyclone poleward and acceleration follows.

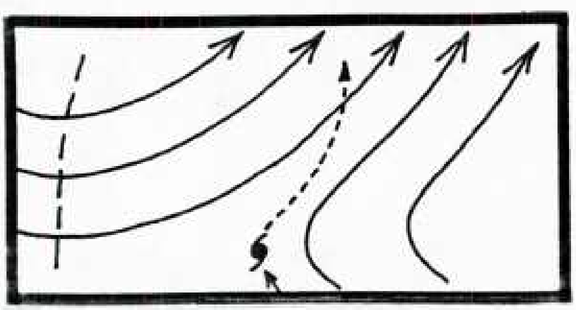
PATTERN RECOGNITION:



SOUTH-SOUTHWESTERLIES (180 to 200 degrees) Generally a very favorable pattern for acceleration. Pattern usually develops from a WEST-SOUTHWESTERLY. Common pattern from early summer to early autumn.

Figure B-2.

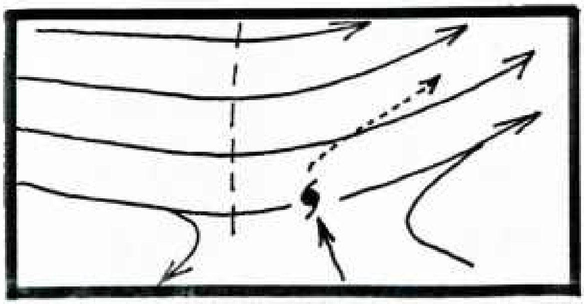
SIGNIFICANT ACCELERATION will commence when wind speeds average 40 knots or greater in Window A. Move the TAPT overlay toward the northwest (with the "⊠" symbol remaining under the baseline) to meet the 40-knot criterion. Refer to TABLE B-1 to determine the recommended acceleration rate.
DURATION & UPPER LIMITS: With this pattern, acceleration is usually very sudden and a fairly rapid extratropical transition normally follows. Thus, most of the acceleration occurs within 24 to 36 hours and may reach speeds above 30 knots (often ahead of those predicted in the acceleration tables).
TRACK: Normally the track will be toward the north-northeast or the north-northwest moving from 10 to 20 degrees left of the upper-level wind pattern.
CAUTION: This pattern often sets-up within 12 hours of acceleration, aided by interaction of the tropical cyclone with the westerlies, a ridge building process often occurs east of the upper-level trough.



WEST-SOUTHWESTERLIES (225 to 255 degrees) Generally the most favorable pattern for a sustained acceleration. A common pattern from late September to early November, also seen from late April to early June.

Figure B-3.

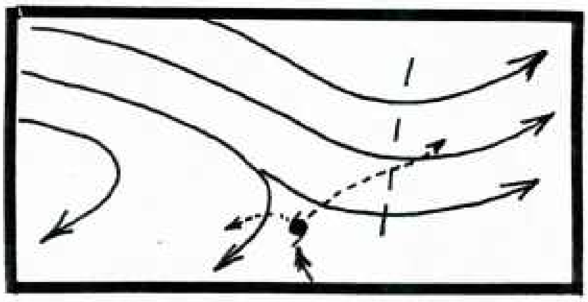
SIGNIFICANT ACCELERATION will commence when wind speeds average 40 knots or greater in Window A. Move the TAPT overlay toward the northwest (with the "⊠" symbol remaining under the baseline) to meet the 40-knot criterion. Refer to TABLE B-1 to determine to recommended acceleration rate.
DURATION & UPPER LIMITS: If this pattern is maintained throughout the acceleration process, the acceleration will normally be sustained for over 30 hours and may well exceed 30 knots before extratropical transition.
TRACK: Given a persistent pattern, the track will recurve toward the northeast and will move from 10 degrees (initially) to 25 degrees (in later stages) left of the upper-level wind pattern.
CAUTION: This pattern can quickly change to a SOUTH-SOUTHWESTERLY which will noticeably affect both the duration and track.



WESTERLIES (260 to 285 degrees)
Generally a favorable pattern for acceleration. Common pattern in high zonal situations, especially in the spring, late autumn and winter months.

Figure B-4.

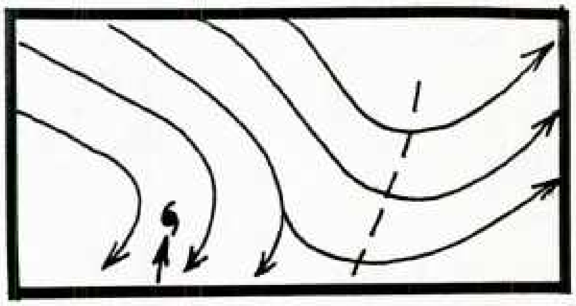
SIGNIFICANT ACCELERATION will commence when wind speeds average 30 knots or greater in Window A. Refer to TABLE B-1 to determine the recommended acceleration rate.
DURATION & UPPER LIMITS: Normally this is a very stable upper-level pattern and the effects of the westerlies on a tropical cyclone will usually weaken the system due to increasing vertical wind shear. Acceleration will peak within 18 to 30 hours with speeds reaching the 20- to 30-knot range.
TRACK: A fairly sharp recurvature track toward the east-northeast moving from 10 to 15 degrees left of the upper-level wind pattern.
CAUTION: In the late fall, winter and early spring, this pattern may be present in the upper-levels while a strong northeast monsoonal flow is dominating the low-levels. In such cases the tropical cyclone will often draw toward an upper trough then turn toward the (west-) southwest with the low-level flow.



WEST-NORTHWESTERLIES (290 to 325 degrees)
Generally an unfavorable pattern for significant acceleration. Common pattern in transition periods, especially in May and November.

Figure B-5.

SIGNIFICANT ACCELERATION should not occur with this pattern. However, some accelertion may occur before the shearing process weakens the tropical cyclone. When wind speeds average 30 knots or greater in Window A the shearing and limited acceleration process should commence. Refer to TABLE B-1 to determine the recommended acceleration rate.
DURATION & UPPER LIMITS: Acceleration will be limited to 12 to 24 hours with the maximum speed generally less than 20 knots.
TRACK: If the tropical cyclone recurves, the track will be toward the northeast and moving 30 to 50 degrees left of the upper-level wind pattern. If a strong northeast monsoon flow is present in the lower levels, the tropical cyclone will normally track west-southwestward with the low-level flow instead.
CAUTION: The more northwest the upper-level wind pattern, the more rapid will be the shearing process and the shorter the acceleration period, if any.



NORTH-NORTHWESTERLY (330 to 360 degrees)
A very unfavorable pattern for acceleration. This pattern can develop from the WEST-NORTHWESTERLY pattern in low zonal situations.

Figure B-6.

ACCELERATION should not occur with this pattern. A northward-moving tropical cyclone would encounter very rapid shearing (within 12 to 24 hours) and would quickly become non-tropical in nature. However, surface wind speeds may remain fairly high for 24 to 36 hours after the shearing process has begun. When this process occurs at relatively low latitudes, 15N to 25N, possible regeneration as a significant tropical cyclone may occur if upper-level wind conditions change fairly rapidly and the tropical cyclone ceases its northward movement.
TRACK: Quasi-stationary or erratic until the shearing is completed, then the surviving low will track with the low-level steering.

TABLE B-1. DETERMINATION OF THE RATE OF ACCELERATION

If the low-level flow:					
≈ 5° north of TC is easterly and	weak	moderate	moderate	strong	strong
and ≈ 5° south of TC is westerly and	strong	strong	moderate	moderate	weak
and if Window B (Figure B-8) is:					
answered YES, then use TABLE	B-2	B-2	B-3	B-4	B-4/ *
answered NO, then use TABLE	B-2	B-3	B-4	B-4/ *	*

* a sustained northward movement and associated acceleration may be doubtful under these conditions. Reevaluate potential.

TABLE B-2. SUDDEN (SIGNIFICANT) ACCELERATION

Average Speed Past 12 Hours	Hours into Acceleration +06	+12	+18	+24	+30	+36	+42
≤ 8 knots	10.6	14.2	18.8	25.0	33.3	44.3	***
9 knots	12.0	15.9	21.2	28.2	37.5	49.8	***
10 knots	13.3	17.7	23.5	31.3	41.6	***	
11 knots	14.6	19.5	25.9	34.4	45.8	***	
12 knots	16.0	21.2	28.2	37.5	***		
13 knots	17.3	23.0	30.6	40.7	***		
14 knots	18.6	24.8	32.9	43.8	***		
15 knots	20.0	26.5	35.3	46.9	***		
16 knots	21.3	28.3	37.6	***			
17 knots	22.6	30.1	40.0	***			
18 knots	23.9	31.8	42.3	***			
19 knots	25.3	33.6	44.7	***			
≥ 20 knots	26.6	35.4	47.1	***			

TABLE B-3. TYPICAL (SIGNIFICANT) ACCELERATION

Average Speed Past 12 Hours	Hours into Acceleration +06	+12	+18	+24	+30	+36	+42	+48	+54
≤ 8 knots	10.0	12.5	15.6	19.5	24.4	30.5	38.1	47.7	***
9 knots	11.3	14.1	17.6	22.0	27.5	34.3	42.9	***	
10 knots	12.5	15.6	19.5	24.4	30.5	38.1	47.7	***	
11 knots	13.8	17.2	21.5	26.9	33.6	42.0	***		
12 knots	15.0	18.8	23.4	29.3	36.6	45.8	***		
13 knots	16.3	20.3	25.4	31.7	39.7	49.6	***		
14 knots	17.5	21.9	27.3	34.2	42.7	***			
15 knots	18.8	23.4	29.3	36.6	45.8	***			
16 knots	20.0	25.0	31.3	39.1	48.8	***			
17 knots	21.3	26.6	33.2	41.5	***				
18 knots	22.5	28.1	35.2	43.9	***				
19 knots	23.8	29.7	37.1	46.4	***				
≥ 20 knots	25.0	31.3	39.1	48.8	***				

TABLE B-4. DELAYED (SIGNIFICANT) ACCELERATION

Average Speed Past 12 Hours	Hours into Acceleration +06	+12	+18	+24	+30	+36	+42	+48	+54	+60	+66
≤ 6 knots	7.0	8.2	9.5	11.1	13.0	15.2	17.7	20.6	25.8	32.2	40.2
7 knots	8.2	9.5	11.1	13.0	15.2	17.7	20.6	25.8	32.2	40.2	***
8 knots	9.3	10.9	12.7	14.8	17.3	20.2	25.3	31.6	39.5	49.8	***
9 knots	10.5	12.3	14.3	16.7	19.5	24.4	30.5	38.1	47.6	***	
10 knots	11.7	13.6	15.9	18.5	21.6	27.0	33.8	42.2	***		
11 knots	12.8	15.0	17.5	20.4	25.5	31.9	39.8	49.8	***		
12 knots	14.0	16.3	19.1	23.9	29.8	37.3	46.6	***			
13 knots	15.2	17.7	20.7	25.9	32.3	40.4	***				
14 knots	16.3	19.1	23.9	29.8	37.3	46.6	***				
≥ 15 knots	---------------- Use Table B-2. -------------										

DISCUSSION:

To this point, the most-recent 200 mb analysis and prognostic charts have been evaluated and an upper-level wind pattern has been identified which has provided a prediction of the best latitude where acceleration will begin, the duration and upper-limits of the acceleration, and the track of a typical tropical cyclone most common to the upper-level wind pattern. Additionally, the rate of acceleration has been determined by evaluating upper- and lower-level winds near to the tropical cyclone.

This technique (TAPT) is a combination of synoptic and statistical predictors which, in most cases, will provide a good approximation of tropical cyclone movement into the mid-latitudes. There are, however, many other factors which the forecaster should consider before applying the results of this technique to the forecast. Some of the meteorological factors which might be at variance with the TAPT forecast are listed below.

1. A weak tropical cyclone, with little or no mid- or upper-level support cannot be expected to draw into the westerlies and accelerate similar to a strong typhoon.

2. A very compact, or midget tropical cyclone with a very tight upper-level circulation may not accelerate unless it is adjacent to a deep-tropospheric steering current.

3. A well-established low-level wind regime which is directed against the upper-level wind pattern which will most often overcome the upper-level steering and move the tropical cyclone southwestward. A good example is a strong northeast monsoon off of Asia and Japan in the late fall through early spring.

4. Rapidly changing upper-level wind patterns that may suggest one forecast scenario then another. Any forecast during this situation is difficult and accordingly, the reliability of TAPT is highly dependent on the identification of the upper-level wind pattern when interaction with the westerlies begins.

5. Movement of the tropical cyclone away from a predicted northward track. Obviously, if the tropical cyclone fails to attain enough latitude in a presumed period of time, then the expected interaction with the westerlies will be delayed or never occur.

6. Interaction with a tropical upper-tropospheric trough (TUTT). If a strong TUTT lies between the tropical cyclone and the main belt of the westerlies, interaction with the westerlies may be denied. The TUTT may weaken the tropical cyclone (vertical wind shear); the TUTT may also slow the tropical cyclone as they interact.

7. Interaction with another tropical cyclone or other warm-core cyclone may cause one or both cyclones to rotate about a common point at the expense of moving toward interaction with the mid-latitude westerlies as would be expected in a single cyclone situation.

8. A signficant displacement of the low-level (surface, 850 or 700 mb) westerlies northward of the upper-level westerlies. In such cases, the surface center must overcome the influence of the low-level steering, which is often in opposition to the upper-level steering, before the tropical cyclone can accelerate. If the upper-level circulation does not shear away from the low-level center and if the tropical cyclone continues the drift northward, then the acceleration will tend to be gradual until the effects of low-level steering have been overcome. Table B-4 can assist in blending in this gradual acceleration.

9. Non-representative analyses and/or prognostic data might produce the wrong interpretation of the upper-level wind regime and affect the viability of a northward-moving track.

If acceleration appears to be occurring much earlier than predicted (more than one degree latitude south), double-check the data and the TAPT results. If the reason for acceleration is not known, only apply further acceleration if it is certain that the acceleration is in response to mid-latitude westerlies and not due to nominal fix accuracies.

If acceleration does not occur as predicted (tropical cyclone is located more than one degree north of predicted latitude) and cannot be explained by one or more of the items (1-9) above, phase in the acceleration to reach the predicted location by 30 hours. If the tropical cyclone exhibits strong shearing of its upper-level circulation, then only a modest (12- to 24-hour) acceleration should be forecast if the low-level steering favors a continued northward track.

If the TAPT results appear to be questionable, i.e. too low of a latitude, check the results against the climatology prediction for that month. If there is a great difference (more than five degrees), the forecaster will have to make a decision consistent with the data on hand.

If it appears that there are no limiting factors to the TAPT results, then the forecaster is encouraged to apply the technique, consistent with good forecast judgement.

CLIMATOLOGY:

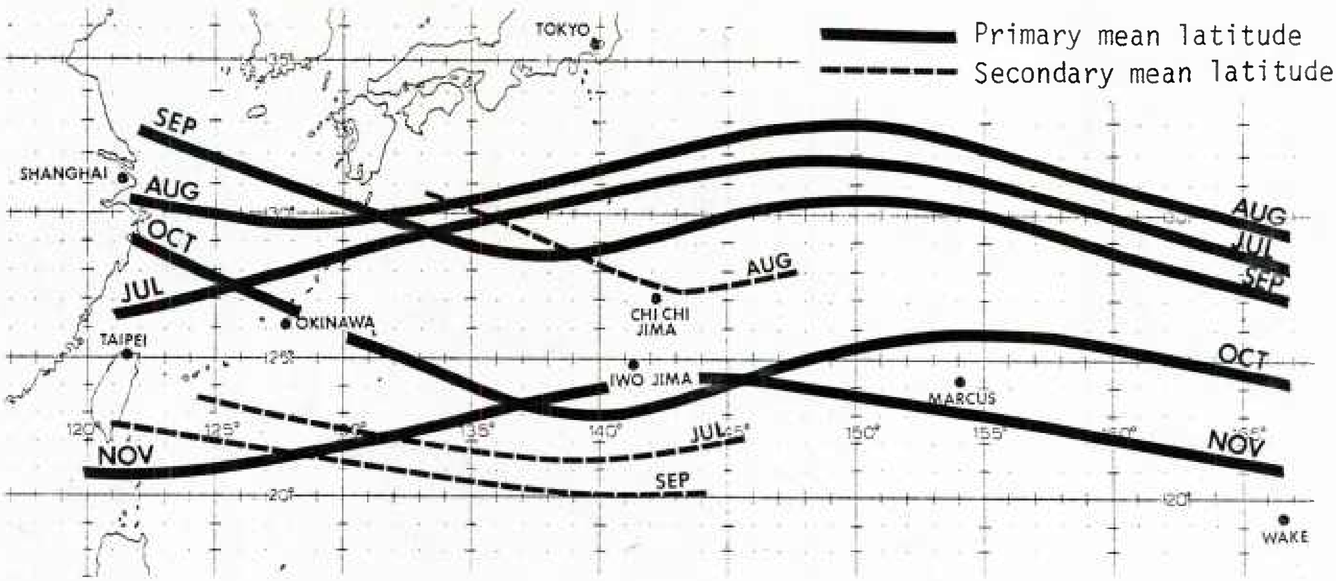


Figure B-7.

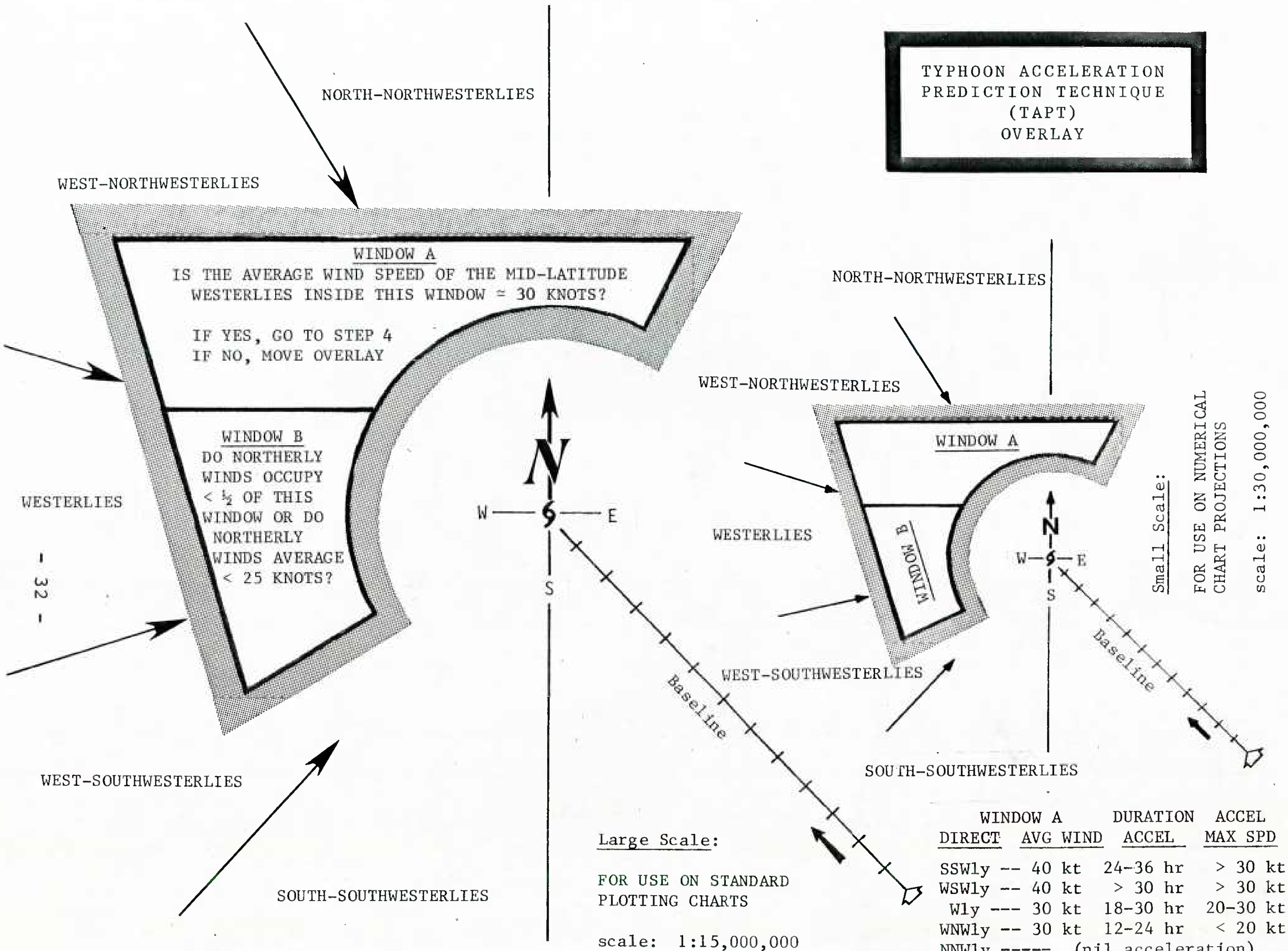
Acceleration of northward-moving tropical cyclones is a fairly common event in the western North Pacific Ocean from July through November. As such, there is a climatology of mean latitudes where initial accelerations tend to occur. In this figure, each month, July through November, has a primary latitude where acceleration begins in the mean. For the months, July through September, there are a sufficient number of cases to suggest a secondary latitude belt where these accelerations might occur.

<u>To Use Climatology</u>: When a forecast cannot be made using TAPT, determine the intersection of the forecast track and each of the mean latitudes for the month (or average of two months). Locate the base (southern extremity) of the mid-latitude westerlies ($\geq$ 30 knots) on the 200 mb chart with a valid time closest to the estimated intersection time (arrival of tropical cyclone near the westerlies).

Complete the following:

	_____	N	(latitude at the base of the westerlies)
-	6		(subtract six degrees)
=	_____	N	
+	_____	N	(latitude of climatological acceleration)
=	_____ / 2	N	(Divide by 2) = _____ N (computed latitude of acceleration)

Use Table B-3 for acceleration rates (enter at 8 knots, if the speed up to the acceleration point is not well-forecast). Apply the forecast acceleration to the track at the computed latitude of acceleration, <u>consistent with good forecast judgement</u>.



WINDOW A DIRECT	WINDOW A AVG WIND	DURATION ACCEL	ACCEL MAX SPD
SSWly	-- 40 kt	24-36 hr	> 30 kt
WSWly	-- 40 kt	> 30 hr	> 30 kt
Wly	--- 30 kt	18-30 hr	20-30 kt
WNWly	-- 30 kt	12-24 hr	< 20 kt
NNWly	-----	(nil acceleration)	

Figure B-8.

APPENDIX C

SUMMARY OF TAPT'S PERFORMANCE DURING THE 1982 TROPICAL CYCLONE SEASON

The 1982 tropical cyclone season was one of the most active in recent years, with respect to the number of northward-moving tropical cyclones. In all, 20 tropical cyclones either moved into the mid-latitudes or were, at one time, forecast to do so. Fourteen of these tropical cyclones eventually moved north of 30N, and one tropical cyclone (Owen) had two distinct northward treks. Thus, 1982 produced 15 tropical cyclone events which can be compared to the 1971-1981 typhoon data set (Appendix A). Additionally, these 15 cases have provided a wide range of forecast situations to evaluate the predictive skill of the Typhoon Acceleration Predicition Technique (TAPT)

Table C-1 provides a comparison between the 15 northward-moving tropical cyclone cases of 1982 and the 11-year data set (1971-1981). This comparison shows that all of 1982's northward-movers accelerated, compared to 88% in the 11-year data set. Mean values from 1982 show that these tropical cyclones began their acceleration about two degrees south of those from the 11-year data set. Although the maximum speed reached in acceleration was attained three hours later and was slightly slower than the 11-year mean, the acceleration ended near the same latitude (33N). Despite the high frequency of accelerating tropical cyclones in 1982, only one (TD 22) reached the 38 kt (70 km/hr) threshold which had been attained by nine tropical cyclones during the previous three-year period (1979-1981). However, when 1982 is compared to the northward-moving tropical cyclones of the previous three years (Table C-2), the annual variability in mean values becomes evident. Although comparisons made during one tropical cyclone season do not necessarily provide a sufficient distribution of representative cases to evaluate the skill of any technique, it is comforting that an evaluation of TAPT was conducted during a year when there was a high frequency of northward-moving tropical cyclones and when the annual mean values on the acceleration phenomenon were in close agreement with the historical means.

TAPT estimates of the latitude where accelerations should have begun were extracted from the JTWC speed of movement worksheets for each of the 15 northward-moving tropical cyclone events of 1982. These estimates were obtained in real-time and represent the latitude most often predicted during the 48-hour period prior to acceleration. Other TAPT estimates, i.e. the rate of acceleration, the duration and upper-limits of the acceleration process, and the basic track of the accelerating tropical cyclone, were derived by applying the final technique (Appendix B) to the 200 mb and surface/gradient-level charts with valid times approximately 24 hours prior to the beginning of each acceleration event. These latter estimates may vary slightly from those obtained, as the

TABLE C-1.

COMPARISON OF THE NORTHWARD-MOVING
TROPICAL CYCLONES OF 1982 AND
THE 1971-1981 STUDY GROUP

	1982	1971-1981
◆ TOTAL NUMBER OF NORTHWARD-MOVING TROPICAL CYCLONES TO REACH 30N	15 *	58
• Number of TCs that accelerated	15	51
Percentage	100%	88%
• Number of TCs attaining 19 kt or greater	13	42
Percentage	87%	72%
• Mean pre-acceleration speed	9 kt	8½ kt
• Mean maximum speed in acceleration	26 kt	28 kt
• Mean period of acceleration	37 hr	34 hr
• Mean latitude at start of acceleration	25N	27N
• Mean latitude at end of acceleration	33N	33N
• Number of TCs starting acceleration north of 32N	0	3
◆ NUMBER OF ACCELERATING TROPICAL CYCLONES ATTAINING 19 KT OR GREATER	13	42
• Number of TCs attaining 27 kt or greater	9	26
Percentage	69%	62%
• Number of TCs attaining 38 kt or greater	1	10
Percentage	8%	24%
• Mean pre-acceleration speed	9½ kt	9 kt
• Mean time to reach $\geq$ 19 kt threshold	28 hr	25 hr

* Typhoon Owen had two distinct acceleration periods (19 to 21 October and 26 to 28 October). After completing its first acceleration, Owen weakened and turned southeastward for several days; then after reorganizing, Owen moved northward once again and underwent its second acceleration (refer to the 1982 Annual Tropical Cyclone Report for further details). Each of these acceleration periods is treated as a separate tropical cyclone event in this comparison.

TABLE C-2. NORTHWARD-MOVING TROPICAL CYCLONES, 1979-1982

1979

1.	IRVING	7 to 30 kt in 42 hrs
2.	JUDY	6 to 13 kt in 30 hrs
3.	KEN	6 to 20 kt in 30 hrs
4.	LOLA	8 to 15 kt in 18 hrs
5.	OWEN	4 to 47 kt in 42 hrs
6.	ROGER	12 to 30 kt in 24 hrs
7.	TIP	7 to 48 kt in 42 hrs
1979 Average		7 to 29 kt in 33 hrs

1980

1.	ELLEN	16 to 34 kt in 24 hrs
2.	LEX	8 to 15 kt in 24 hrs
3.	MARGE	11 to 29 kt in 24 hrs
4.	ORCHID	16 to 35 kt in 12 hrs
5.	SPERRY	Did not accelerate
6.	THELMA	12 to 43 kt in 30 hrs
7.	VERNON	9 to 53 kt in 36 hrs
8.	WYNNE	7 to 44 kt in 54 hrs
9.	ALEX	14 to 34 kt in 12 hrs
10.	BETTY	7 to 23 kt in 36 hrs
11.	DINAH	13 to 35 kt in 30 hrs
1980 Average		11 to 35 kt in 28 hrs

1981

1.	FREDA	10 to 18 kt in 12 hrs
2.	JUNE	12 to 19 kt in 18 hrs
3.	OGDEN	13 to 18 kt in 12 hrs
4.	PHYLLIS	11 to 18 kt in 6 hrs
5.	SUSAN	5 to 10 kt in 18 hrs
6.	THAD	5 to 45 kt in 36 hrs
7.	VANESSA	Did not accelerate
8.	AGNES	Did not accelerate
9.	BILL	11 to 42 kt in 36 hrs
10.	DOYLE	7 to 35 kt in 36 hrs
11.	ELSIE	10 to 45 kt in 42 hrs
12.	GAY	10 to 43 kt in 36 hrs
1981 Average		10 to 29 kt in 25 hrs

1982

1.	PAT	10 to 27 kt in 48 hrs
2.	RUBY	13 to 26 kt in 24 hrs
3.	SKIP	18 to 28 kt in 24 hrs
4.	VAL	17 to 28 kt in 18 hrs
5.	BESS	6 to 33 kt in 36 hrs
6.	CECIL	6 to 14 kt in 30 hrs
7.	ELLIS	7 to 28 kt in 42 hrs
8.	GORDON	5 to 22 kt in 30 hrs
9.	JUDY	6 to 34 kt in 54 hrs
10.	KEN	6 to 23 kt in 54 hrs
11.	LOLA	9 to 22 kt in 36 hrs
12.	TD 22	11 to 38 kt in 42 hrs
13.	MAC	8 to 28 kt in 48 hrs
14a.	OWEN	8 to 22 kt in 48 hrs
14b.	OWEN	6 to 15 kt in 24 hrs
1982 Average		9 to 26 kt in 37 hrs

1979-1982

45 tropical cyclones (events)
3 did not accelerate
42 accelerating tropical cyclones

1979-1981 Average 9 to 29 kt in 31 hrs

TABLE C-3. COMPARISON OF TROPICAL CYCLONE MOVEMENT AND TAPT ESTIMATES

ACTUAL / TAPT	UPPER WIND PATTERN / ACCEL TABLE	LAT START OF ACCEL / LAT	DURATION OF ACCEL / DURATION	MAX SPEED IN ACCEL / UPPER-LIMITS	MEAN HEADING IN ACCEL / TRACK	COMMENTS
TY PAT	W / B-3	20N / 19N	48 hr / 18-30 hr	27 kt / 20-30 kt	060 T / ENE	TAPT DID QUITE WELL WITH TY PAT. 24 HOURS INTO ACCELERATION, PAT'S RATE OF ACCELERATION SLOWED, ALTHOUGH MAX SPEED OCCURRED AT 48 HRS.
TY RUBY	SSW / B-2	24N / 23N	30 hr / 24-36 hr	26 kt / >30 kt	015 T / NNW-NNE	RUBY DID NOT REACH SPEEDS OVER 30 KT AS PREDICTED. RUBY SLOWED AS IT TRANSITIONED INTO AN EXTRATROPICAL SYSTEM.
TS SKIP	W / B-3	24N* / 18N	24 hr / 18-30 hr	28 kt / 20-30 kt	060 T / ENE	* SKIP DEVELOPED TOO CLOSE TO THE WESTERLIES FOR TAPT TO FULLY ESTIMATE SKIP'S INITIAL AND FORECAST SPEEDS OF MOVEMENT.
TS VAL	W / B-3	24N* / 18N	18 hr / 18-30 hr	28 kt / 20-30 kt	060 T / ENE	* VAL DEVELOPED TOO CLOSE TO THE WESTERLIES FOR TAPT TO FULLY ESTIMATE VAL'S INITIAL AND FORECAST SPEEDS OF MOVEMENT.
STY BESS	SSW / B-3	26N / 25N	36 hr / 24-36 hr	33 kt / >30 kt	350 T / NNW-NNE	TAPT DID QUITE WELL WITH STY BESS.
TY CECIL	SSW / B-4**	29N / 30N	30 hr / 24-36 hr	14 kt / >30 kt	350 T / NNW-NNE	CECIL WAS NOT A STRONG CANDIDATE FOR SIGNIFICANT ACCELERATION BECAUSE A TUTT SEPARATED IT FROM THE MID-LATITUDE WESTERLIES.
TY ELLIS	SSW / B-4**	28N / 28N	42 hr / 24-36 hr	28 kt / >30 kt	010 T / NNW-NNE	ELLIS'S RATE OF ACCELERATION WAS HIGHER IN THE 30- TO 42-HOUR PERIOD THAN THAT PREDICTED BY TABLE B-4**.
TY GORDON	WNW / B-3	29N / 31N	30 hr / 12-24 hr	22 kt / <20 kt	050 T / NE	A RAPIDLY CHANGING UPPER WIND PATTERN MADE THIS A DIFFICULT FORECASTING SITUATION; HOWEVER, TAPT ESTIMATES WERE MORE THAN ADEQUATE.
TY JUDY	WSW / B-4**	26N / 24N	54 hr / >30 hr	34 kt / >30 kt	050 T / NE	JUDY'S RATE OF ACCELERATION WAS HIGHER IN THE 42- TO 54-HOUR PERIOD THAN THAT PREDICTED BY TABLE B-4**.
TY KEN	W / B-4**	23N / 21N	54 hr / 18-30 hr	23 kt / 20-30 kt	030 T / ENE	KEN MOVED MORE NORTHWARD AND DURATION OF THE ACCELERATION LASTED LONGER THAN PREDICTED. TABLE B-4** PROVIDED GOOD SPEED ESTIMATES.
TS LOLA	WSW / B-3	29N / 29N	36 hr / >30 hr	32 kt / >30 kt	055 T / NE	TAPT DID QUITE WELL WITH TS LOLA.
TD 22	WSW / B-3	22N / 21N	42 hr / >30 hr	38 kt / >30 kt	025 T / NE	TABLE B-4** WOULD HAVE DONE MUCH BETTER THAN B-3 WITH TD 22.
STY MAC	WSW / B-4**	21N / 22N	48 hr / >30 hr	28 kt / >30 kt	030 T / NE	MAC MOVED MORE NORTHWARD THAN WAS PREDICTED FOR THIS UPPER WIND PATTERN. OTHERWISE, TAPT'S ESTIMATES** WERE QUITE GOOD.
TY OWEN	WSW / B-4**	19N / 21N	48 hr / >30 hr	22 kt / >30 kt	020 T / NE	OWEN MOVED MORE NORTHWARD THAN WAS PREDICTED FOR THIS UPPER WIND PATTERN. OWEN ACCELERATED SLIGHTLY SLOWER THAN TABLE B-4** PROVIDED.
TY OWEN	W / B-3	29N / 28N	24 hr / 18-30 hr	15 kt / 20-30 kt	020 T / ENE	SECOND TIME AROUND AND DISSIPATING, OWEN MOVED MORE NORTHWARD AND SLOWER THAN PREDICTED.

* SYSTEM DEVELOPED TOO CLOSE TO THE WESTERLIES FOR TAPT TO FULLY ESTIMATE ITS INITIAL AND FORECAST SPEEDS OF MOVEMENT. BEST TRACK PERIOD MAY WILL DEPICT THE LATTER HALF OF THIS SYSTEM'S LIFESPAN; THUS, SPEED OF MOVEMENT AND DURATION OF ACCELERATION MAY BE DOUBTFUL AS GIVEN BY BEST TRACK DATA.

** TAPT TABLE B-4 WAS NOT AVAILABLE FOR USE DURING THE 1982 TROPICAL CYCLONE SEASON. ESTIMATES OF SPEED OF MOVEMENT ARE SLOWER THAN THOSE AVAILABLE DURING THE SEASON WHEN TABLE B-3 WAS USED.

TABLE C-4. COMPARISON OF TROPICAL CYCLONE MOVEMENT AND TAPT ACCELERATION RATES

Tropical Cyclone	TAPT Estimates	Pre-accel Speed	Actual/TAPT Speeds of Movement +06	+12	+18	+24	+30	+36	+42	+48	+54	+60	+66	+72
PAT (04)		10 kt	11	15	18	23	24	23	25	27	--	--	--	--
PATTERN:	W'ly	B-2	13	18	24	31	42	**						
DURATION:	18-30 hr	B-3 —	13	16	20	24	31	38	48	**				
UPPER-LIMITS:	20-30 kt	B-4	12	14	16	19	22	27	34	42	**			
RUBY (05)		13 kt	15	18	23	23	26	--	--	--	--	--	--	--
PATTERN:	SSW'ly	B-2 —	17	23	31	41	**							
DURATION:	24-36 hr	B-3	16	20	25	32	40	50	**					
UPPER-LMITS:	> 30 kt	B-4	15	18	21	26	32	40	**					
SKIP (07)		18 kt	19	22	24	28	27	23	--	--	--	--	--	--
PATTERN:	W'ly	B-2	24	32	42	**								
DURATION:	18-30 hr	B-3 —	23	28	35	44	**							
UPPER-LIMITS:	20-30 kt	B-4	(use Table B-3)											
VAL (08)		17 kt	23	26	28	28	--	--	--	--	--	--	--	--
PATTERN:	W'ly	B-2	23	30	30	**								
DURATION:	18-30 hr	B-3 —	21	27	33	42	**							
UPPER-LIMITS:	20-30 kt	B-4	(use Table B-3)											
BESS (11)		6 kt	9	9	13	15	24	33	37	14	--	--	--	--
PATTERN:	SSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	24-36 hr	B-3 —	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4	7	8	10	11	13	15	18	21	26	32	40	**
CECIL (12)		6 kt	8	8	10	13	14	10	9	8	6	10	10	--
PATTERN:	SSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	24-36 hr	B-3	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4 —	7	8	10	11	13	15	18	21	26	32	40	**
ELLIS (14)		7 kt	8	9	11	13	17	21	28	--	--	--	--	--
PATTERN:	SSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	24-36 hr	B-3	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4 —	8	9	11	13	15	18	21	26	32	40	**	
GORDON (16)		5 kt	9	10	18	18	22	18	18	--	--	--	--	--
PATTERN:	WNW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	12-24 hr	B-3 —	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	< 20 kt	B-4	7	8	10	11	13	15	18	21	26	32	40	**
JUDY (19)		6 kt	7	8	9	10	12	16	22	28	34	--	--	--
PATTERN:	WSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	> 30 hr	B-3	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4 —	7	8	10	11	13	15	18	21	26	32	40	**
KEN (20)		6 kt	9	8	11	11	15	10	15	22	23	22	--	--
PATTERN:	W'ly	B-2	11	14	19	25	33	44	**					
DURATION:	18-30 hr	B-3	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	20-30 kt	B-4 —	7	8	10	11	13	15	18	21	26	32	40	**
LOLA (21)		9 kt	11	14	18	22	28	32	--	--	--	--	--	--
PATTERN:	WSW'ly	B-2	12	16	21	28	38	50	**					
DURATION:	> 30 hr	B-3 —	11	14	18	22	28	34	43	**				
UPPER-LIMITS:	> 30 kt	B-4	11	12	14	17	20	24	31	38	48	**		
TD 22 (22)		11 kt	15	20	17	21	29	32	38	--	--	--	--	--
PATTERN:	WSW'ly	B-2	15	20	26	34	46	**						
DURATION:	> 30 hr	B-3 —	14	17	22	27	34	42	**					
UPPER-LIMITS	> 30 kt	B-4	13	15	18	20	26	32	40	50	**			
MAC (23)		8 kt	9	14	11	17	18	23	22	28	19	18	--	--
PATTERN:	WSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	> 30 hr	B-3	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4 —	9	11	13	15	17	20	25	32	40	50	**	
OWEN (26a)		8 kt	10	10	11	13	15	17	19	22	20	17	--	--
PATTERN:	WSW'ly	B-2	11	14	19	25	33	44	**					
DURATION:	> 30 hr	B-3	10	13	16	20	24	30	38	48	**			
UPPER-LIMITS:	> 30 kt	B-4 —	9	11	13	15	17	20	25	32	40	50	**	
OWEN (26b)		6 kt	7	8	10	15	--	--	--	--	--	--	--	--
PATTERN:	W'ly	B-2	11	14	19	25	33	44	**					
DURATION:	18-30 hr	B-3 —	10	13	16	20	24	31	38	48	**			
UPPER-LIMITS:	20-30 kt	B-4	7	8	10	11	13	15	18	21	26	32	40	**
		Accel Table												

technique evolved, during the season -- but they do not represent any significant departure from those earlier estimates. Each TAPT estimate was then compared to the corresponding best track data and those comparisons are presented in Tables C-3 and C-4. An explanation for each of those tables follows.

Table C-3 (example):

ACTUAL / TAPT	UPPER WIND PATTERN / ACCEL TABLE	LAT START OF ACCEL / LAT	DURATION OF ACCEL / DURATION	MAX SPEED IN ACCEL / UPPER-LIMITS	MEAN HEADING IN ACCEL / TRACK	COMMENTS
TY PAT	W	20N	48 hr	27 kt	060 T	TAPT DID QUITE WELL WITH TY PAT. 24 HOURS INTO ACCELERATION, PAT'S RATE OF ACCELERATION SLOWED, ALTHOUGH MAX SPEED OCCURRED AT 48 HRS.
	B-3	19N	18-30 hr	20-30 kt	ENE	

This table compares four of the five TAPT estimates with the actual best track values. In this case, TAPT's prediction of 19N was very close to the actual latitude (20N) where Pat began to accelerate. The duration of the acceleration process was longer than predicted by TAPT; however, as the comments section indicates, Pat's rate of acceleration slowed considerably after 24 hours. TAPT's estimates of the maximum speed (20 to 30 kt) and track (toward the ENE) compare quite favorably with the actual values.

Table C-4 (example):

Tropical Cyclone	TAPT Estimates	Pre-accel Speed	+06	+12	+18	+24	+30	+36	+42	+48	+54	+60	+66	+72
			Actual/TAPT Speeds of Movement											
PAT (04)		10 kt	11	15	18	23	24	23	25	27	--	--	--	--
PATTERN:	W'ly	B-2	13	18	24	.31	42	**						
DURATION:	18-30 hr	B-3 —	13	16	20	24	31	38	48	**				
UPPER-LIMITS:	20-30 kt	B-4	12	14	16	19	22	27	34	42	**			

This table compares TAPT's estimate of the rate of acceleration with the actual best track values. The rate of acceleration is contained within the speed of movement values; these values have been rounded-off from those given in their respective tables. In this case, Table B-3 (note the bar extending to the right) was selected by the technique as the best table for acceleration speeds. As can be seen, through 24 hours, Table B-3 provided a very good approximation of Pat's speed of movement.

Table C-5 provides an an evaluation of TAPT's prediction errors for the four estimates given in Table C-3. Of note, the mean duration of the acceleration was approximately six hours longer than predicted and the mean direction of movement was slightly northward than the technique estimated. These errors show that approximately 60 percent of all latitude and track predictions, and nearly 80 percent of all duration and upper-limits of acceleration predictions were within nominal limits of the actual values.

TABLE C-5. EVALUATION OF TAPT'S PREDICTION ERRORS

Tropical Cyclone	Latitude*	Duration**	Upper-Limits**	Track***
TY PAT	- 1	+ 24	+ 2	+ 5
TY RUBY	- 1	0	- 5	- 15
TS SKIP	n.a.	0	+ 3	+ 5
TS VAL	n.a.	- 6	+ 3	+ 5
STY BESS	- 1	+ 6	0	+ 10
TY CECIL	+ 1	0	- 16	+ 10
TY ELLIS	0	+ 12	- 3	- 10
TY GORDON	+ 2	+ 12	+ 3	- 5
TY JUDY	- 2	0	0	- 5
TY KEN	- 2	+ 30	- 2	+ 35
TS LOLA	0	0	0	- 10
TD 22	- 1	0	0	+ 20
STY MAC	+ 1	0	- 3	+ 15
TY OWEN	+ 2	0	- 9	+ 25
TY OWEN	- 1	0	- 10	+ 45
Mean Error	- 0.2 deg	+ 5.2 hr	- 2.5 kt	+ 11.0 deg
Absolute Magnitude	1.1 deg	6.0 hr	3.9 kt	14.6 deg
General Statement	8 of 13 cases were within one degree	11 of 15 cases were within six hours	12 of 15 cases were within five knots	9 of 15 cases were within ten degrees

* TS Skip and TS Val were not compared for latitude because their best tracks began north of the predicted latitude and acceleration was underway from the first best track position.

** When TAPT provides a range, e.g. 20-30 kt, the median value (e.g. 25 kt) is used to compare the TAPT estimate with the actual value. When TAPT provides an upper- or lower-limit, i.e. > 30 or < 20, the actual value is compared to ≥ 31 and ≤ 19, respectively.

*** TAPT estimates for track are compared to the overall best track during the acceleration period using the following values:

NNW - NNE = 360°; NE = 045°; and ENE = 065°.

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